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The thermodynamic efficiency of energy complex enterprises processing raw gas condensate

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Abstract

This paper provides analysis of thermodynamic efficiency of an energy complex of gas and gas condensate processing enterprises interrelated with primary technological facilities involved in continuous fuel, heat and electrical energy generation and consumption processes. The analysis is based on aggregate-decomposition method used for system analysis and synthesis of complex objects. Exergy balance sheets for gas condensate processing enterprise are drawn up as a Grassmann diagram. Potential of several production facilities of an enterprise involved in processing raw hydrocarbons from gas condensate is evaluated and the possibility of using their engineering design for fuel and heat production systems is discussed.

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Keywords: energy complex; thermodynamic analysis; system efficiency; gas and gas condensate processing;

1. Introduction

The energy complex of gas and gas condensate processing enterprises (GGCPC) interrelates with the main industrial processes in the continuous cycles of fuel generation and consumption, heat and electrical energy, and with external systems of raw material resources, fuel and energy resources (FER) and water resources. At the present time for their own needs of hydrocarbon processing industry consumes up to 10 % FER on the amount of composition of the processed crude hydrocarbons (CHC). However, in all significant reserves GGCPC recycled energy resources (RER), including combustible waste, the use of which does not exceed 14 % of available capacity. This is due to the low energy efficiency of separate recycling equipment, the absence of specific power plants, taking

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into account the specific requirements of GGCPC customers, mismatched dynamic characteristics of generation and consumption of energy and other causes. So the development strategy and improvement ways forming energy complex (EC) of each GGCPC needs its research in the interrelation with the technological system (TS) taking into account all influencing factors on the basis of the system analysis and compound objects synthesis methodology [1].

The accumulated experience of scientific and applied research based on mathematical modeling and experimental knowledge of technological processes of gas processing and power supply systems allowed to create methods and algorithms for evaluating the performance of enterprises and industrial and economic systems based on the criteria of the quality of their performance as a whole. This made structural identification of technical systems in general [2, 3] or developed economic models of objects such as the oil and gas industry as a whole [4, 5]. At the same time, GGCPC EC has some specific properties, the main of which are its structure and operating modes dependence on the technological topology of the main processing procedures (which in turn is determined by the composition of raw materials), the period of the life cycle of hydrocarbon fields, from construction of the facility, and ending its decommissioning (including the relationship with the external system to ensure FER), ecological and climatic conditions of the region the object location and economic factors.

Our own theoretical and experimental studies of large enterprises EC on processing of various heterogeneous CHC condensate fields [1, 6-10] showed that the thermodynamic analysis of such complex systems of power technology will significantly restrict the scope of the search for optimal solutions. While multivariating problem of the EC structural and parametric synthesis can be solved on the basis of the decomposing and parametric method on the first research stages with the elementwise modification generation of the only innovative and rational scheme and parametric solutions, which are effective in the changing economic conditions at all life cycle stages of the main technological processes.

2. Model of energy complex

The analysis of the FER consumption and generation in separate GGCPC elements with the potential identification of its thermodynamic effectiveness increase is completed for the object, the structure of which is in the form of the block-hierarchical model. This structure is shown in fig. 1. Each hierarchy level shows the following internal and external connections: I – external assurance systems (CHC, FER, water) and sanitation systems processing plant; II – connection ventures with external systems; communication energy complex on the fuel system; GGCPC connection with systems the energy complex and manufacture of fuel system; III – communication energy complex systems with their installations and communications facilities of the fuel system to their settings; while EC systems and TS processes include a number of facilities of level IV, which contain energy-technological units (elements of level V), simultaneously relative to two elements of the level II – to the TS and the EC; IV – communications installations with the systems, manufacture, devices; V – communication between devices and resources. Last VI hierarchy level comprises a matrix of devices matching the level of the elements V mathematical analysis of the description, the optimization of consumption and generation FER and water.

The core processes are considered as the basic elements. These processes include a number of facilities with virtually the same process structure for all GGCPC (CHC separation, drying, cleaning) and facilities typical for single objects (processes of technical carbon, sulfur, helium).

EC systems are grouped in three basic systems by type of the consumable and generated energy supplies (fuel, electro-technical and thermo-technical) and the intraproductive subsystem, which includes technological and recycling water supply, air supply, neutral gas supply, water removal.

The main EC elements have complicated internal connections and multifunctional interrelation with the TS, its separate facilities and instruments are the fuel and energy supplies producers (for example degasser, CHC column-stabilizer, energy-technological waste-heat boilers, technological pipe heaters utilizers).

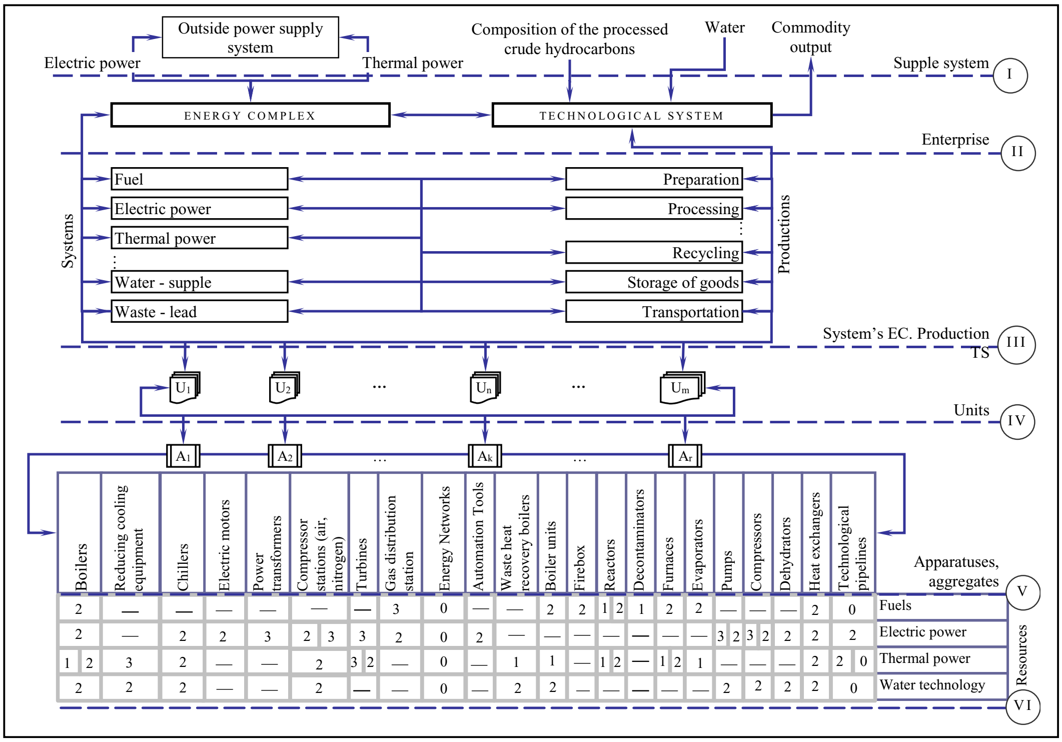

Fig. 1. Block-hierarchical structure of the EC and TS: 0 – transportation; 1 – generation; 2 – consumption; 3 – transformation.

The design parameters and operating modes depend on the quality of the feedstock, the range of products and other factors listed above. Therefore, improving the efficiency and structural and parametric optimization of these systems make it possible to solve the problem for the whole complex.

3. Methods

Further development of EC and TS that utilize and produce energy capacitors with varying potential has been performed on the basis of thermodynamic analysis and systemic efficiency parameters evaluated as a result of experimental works [1] and mathematical simulation [10].

In order to perform thermodynamic evaluation, we developed functional models, i.e. exergy balance sheets [10], using exergetic efficiency (η_{ex}) as an all-purpose indicator of the object thermodynamic efficiency. This parameter was calculated both for individual elements according to the hierarchy level (Fig. 1) and for the whole GGCPC

$$\eta_{ex} = \frac{\sum ex_I}{\sum ex_O} = 1 - \frac{\sum ex_L}{\sum ex_I}, \qquad (1)$$

where Σex_I, Σex_O, Σex_L are the exergy amount at the input, output and losses in the element (device, installation, production, system, enterprise).

The GGCPC EC and TS efficiency analysis can include all types of the delivered exergy, regardless of the fact, that it can be changed in the element, or the analysis can include in calculation its part, which can be changed. In many processes and installations of GGCPC chemical exergy of material practically does not change. The main part of it related to the heat of combustion usually remains unchanged. And this part has the absolute value, which is much larger than exergy losses of all process stages.

In general, the chemical exergy ex_C of product and raw hydrocarbon streams was calculated by the approximate relationships [11]:

- for gaseous hydrocarbons

$$ex_C = 0{,}95Q_H \tag{2}$$

- for liquid hydrocarbons

$$ex_C = 0{,}975Q_H \tag{3}$$

where Q_H is the higher calorific value of a substance.

Together with the energetic efficiency ratios, rationalization balances used in the rationalization of consumption and generation FER, as well as water consumption and wastewater:

- energy – technological (ETB)

$$\eta_{\mathrm{R\ ETB}} = 1 - \frac{E_{\mathrm{r}}}{E_{\mathrm{b}}} \tag{4}$$

- fuel

$$\eta_{\mathrm{R}\ F} = 1 - \frac{F_{\mathrm{r}}}{F_{\mathrm{b}}} \tag{5}$$

- water consumption

$$\eta_{\mathrm{R}\ W} = 1 - \frac{W_{\mathrm{r}}}{W_{\mathrm{b}}} \tag{6}$$

- wastewater

$$\eta_{\mathrm{R}\ L} = 1 - \frac{L_{\mathrm{r}}}{L_{\mathrm{b}}} \tag{7}$$

where E_r, E_b are the reduced energy consumption, calculated on the balance of power technology for the base and rational (alternative) object option; F_b, W_b, L_b, F_r, W_r, L_r – the specific fuel consumption, water consumption and water disposal for the normalized and the optimal variant of TS and EC of enterprises.

Characteristics of the baseline scenario have been determined experimentally at actual facilities [1] while balance optimization has been performed using previously developed software [13, 14].

The system of energetic efficiency parameters also includes the RER utilization ratio which accounts for combustible waste used by facilities to generate thermal energy for their own needs (caloric intake, cooling and electricity generating).

$$\eta_{\mathrm{e.u}}^{\mathrm{RER}} = \sum_{t=0}^{\tau} \sum_{j=1}^{n} \frac{Q_{jt}^{\mathrm{RER}}}{Q_{jt\mathrm{a.h}}^{\mathrm{RER}}} \tag{8}$$

where Q_{jt}^{RER}, $Q_{jt\mathrm{a.h}}^{\mathrm{RER}}$ are the thermal energy obtained by utilization of RER, and the available heat of RER in the production of *j* in time period *t*.

Parameters of thermodynamic (1) and systemic efficiency of an energy complex (3) – (8) have been included into a complex criterion with maximal value corresponding to most optimal structure and functional parameters of the EC

$$U = \sum_{i=1}^{x} \gamma_i \overline{u_i} \tag{9}$$

Rank coefficients γi in (9) have been determined using analytic hierarchy process [12] to compare ui parameters with pairwise comparison matrices and further rate them according to the measure of their significance.

Criterion (9) can be used at any level in the company hierarchy, for example, to analyze the effectiveness of existing systems of EC – fuel, thermo-technical, electrical, in conjunction with industries of TS, or structural and parametric synthesis of EC under construction and modernization of objects.

If the energetic efficiency, rationalization coefficients of balance (2) - (7) and RER efficiency coefficient (8) are used as the partial criteria (1), then the vector test maximum

$$U = 0{,}417\overline{\eta}_{\mathrm{R\,ETB}} + 0{,}263\overline{\eta}_{ex} + 0{,}16\overline{\eta}_{\mathrm{R}\,F} + 0{,}097\overline{\eta}_{\mathrm{R}\,L} + 0{,}062\overline{\eta}_{\mathrm{R}\,W} \tag{10}$$

allows to identify the most effective solution among the many alternatives options.

The thermodynamic efficiency of the energy-technological enterprise systems evaluation in conjunction with an external system to ensure fuel and energy resources was made by the exergy balance of the hierarchical level. For the enterprise with the energy and water supply according to scheme in Fig. 1 it looks like

$$ex_R + ex_{Q_\Pi} + ex_{L_\Pi} + ex_W = ex_P + ex_{Q_\mathrm{B}} + ex_{L_\mathrm{B}} + ex_S + ex_D + \Sigma D \tag{11}$$

here ex_R, ex_W, ex_P, ex_S, ex_D – exergy of raw materials, water, products, drains, waste; ex_{Q_Π}, $\left(ex_{Q_\mathrm{B}}\right)$ and ex_{L_Π}, $\left(ex_{L_\mathrm{B}}\right)$ – exergy consumed (given the external system) of thermal and electrical energy; ΣD – exergy loss of material and energy flows.

GGCPC is considered as a system. Optimization of this system is performed according to the criterion of thermodynamic losses. This optimization is to minimize the sum ($ex_S + ex_D + D$).

The fuel network of the same GGCPC is an element both of the EC and TS. The exergy balance of such fuel network is given by the equation

$$ex'_{PG} + ex_{FG} + ex_{FS} = ex''_{PG} + ex_{GQ} + ex_D + \Sigma D \tag{12}$$

here ex'_{PG}, $\left(ex''_{PG}\right)$, ex_{FG}, ex_{FS}, ex_{GQ}, ex_D – exergy process gases at the input (output), exergy of the fuel gas from commodity production network, exergy of consumed combustible waste of TS, exergy of gas on the production of thermal energy in industrial boiler, exergy waste (including unused combustible gases); ΣD – exergy loss in gas consumption processes.

The best type of fuel system corresponds not only to minimum of losses and waste, but also minimum gas consumption of the marketable product network: (exFG + exD + D) → min.

4. Results and Discussion

Exergetic balance sheets (11), (12) certain industries of GGCPC designed as Grassmann charts, one of which is shown in Fig. 2.

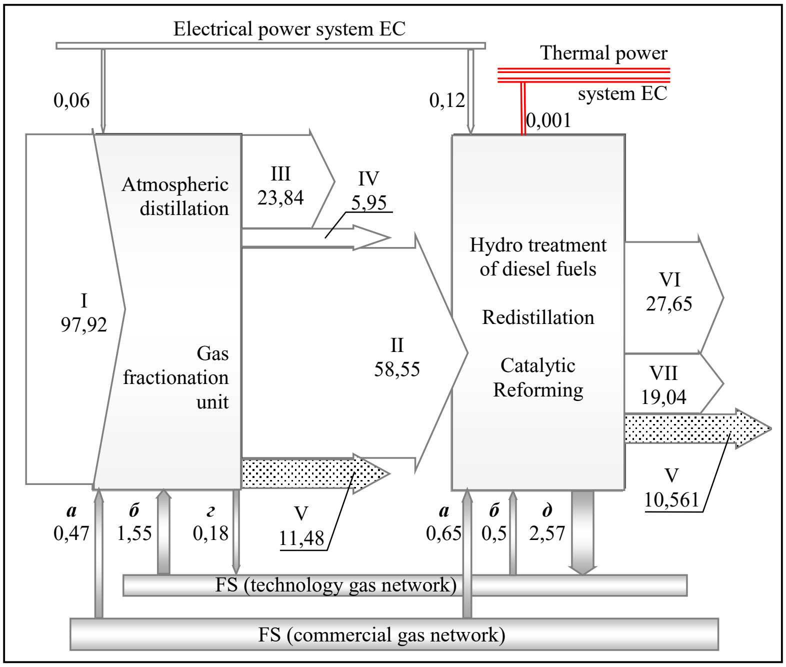

Fig. 2. Exergy balance, %, gas condensate processing units ***process streams***: I – stable condensate and natural gas liquids; II – raw hydrotreatment of diesel fuels; III – boiler and furnace fuels; IV – propane-butane fraction and butane; V – losses; VI – gasoline fractions; VII – diesel fuel; ***gas***: ***a*** – fuel gas in commercial network EPGC; ***б*** – fuel gas domestic production; ***г*** – stabilizing gas to the atmospheric distillation; ***д*** – hydrogen-containing gas, hydrocarbon gas (hydrotreatment of diesel fuels), stabilizing gas (the catalytic reforming units).

For the gas and gas condensate processing perfomances shown in Fig. 2, the exergetic efficiency $\eta_{ex} \approx 0{,}8$ if we take all types of exergy into account, or $\eta'_{ex} \approx 0{,}27$, if the calculations ignore the non-fuel hydrocarbon streams. Exergetic efficiency η_{ex} and η'_{ex}, %, a wide profile manufactures of GGCPC, defined by (1) and balance calculations using software [13, 14], have the following meanings:

η_{ex} η_{ex}

– gas dehydration and topping....90.5 9.9
– cleaning gas (natural, degassing and stabilization)............79.8 11.3
– condensate stabilization and recycling of drains...91.4 8.3
– sulfur production.......58.0 19.1
– processing of gas condensate....78.3 26.8

There is the considerable potential of the energy efficiency in a primary processing facilities of oil, gas and gas condensate - gas drying, degassing and stabilization of liquid-phase raw material, which are included in the structure of not only EPGC, but also are the main technological fuel-consuming units (excluding most energy-intensive compressor station) gas and gas condensate crafts. In particular, the absorbent regeneration units with evaporators fire type gas dehydration installations in its initial preparation to transport the existing condition characterized by high fuel consumption unused thermodynamic potential – exergy efficiency is 57%. Exergy currents flue gas, the gas-vapor mixture leaving the stripper evaporator, degassing gases are waste and not used for useful purposes.

Completed studies thermodynamic drying installations and related gas cleaning installations have allowed developing technical solutions for implementation of the identified potential gas saving in regeneration units absorbents [15 – 17]. The proposed structural - parametric direction of the modernization of these installations can reduce fuel gas consumption of the enterprise network to 30-36%.

For gas enterprises the solution of utilization questions of the low pressure process gas is more important, because it allows to create practically closed-loop environmentally safe EC systems on the basis of its own energy-generated sources [18] with minimum of environmental discharge.

5. Conclusion

The performed thermodynamic analysis of the hydrocarbon raw processing enterprises efficiency allowed to determine the potential of each of the productions and to assess the feasibility of this potential. It was found that the greatest potential for energy efficiency improvement is concentrated in the elements that make up the fuel and thermal systems. These systems should be considered in conjunction with external sources to ensure fuel and energy resources. There are technical solutions with the modernization of the energy-technological systems individual elements for realization of the energy efficiency potential.

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